NEW HAZARDS IN THE UNDERGROUND COAL MINING ENVIRONMENT CAUSED BY THE INTRODUCTION OF RADIO REMOTE AND OTHER ELECTRONIC CONTROLS

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SUMMARY

The introduction of remote controls and automated systems in the South African industry has dramatically increased during the last years of the 20th century. This has been necessary due to the increased demand for higher and safer production.

As labour is the greatest cost component in the production cycle, optimum utilisation of the labour force had to be insured. In order to do this the necessary tools "automation and remote control" had to be developed to assist in obtaining maximum and safer production. The automation of coal cutting equipment includes areas such as information systems, performance and equipment health monitoring of machines. One of the most important rationales for developing and introducing such systems was to enhance the safety of workers in the section by removing the operators from the dangerous area in the heading. Actual experience has however shown that in cases where the equipment and processes were not adequately implemented and maintained, the risk that workers were subjected to, actually increased through the introduction of such equipment.

This paper relates some of the problems, human financial and technical, that were caused by the introduction of automated systems. It then proposes the requirements for such systems to be more safely implemented in the future while at the same time obtaining the maximum productivity benefit.

INTRODUCTION

The mining industry of South Africa contributes substantially to the national economy, both in terms of contribution to foreign exchange earnings and to the gross domestic product (GDP). South Africa's mineral sales for 1997 were R66,2 billion.

Primary mineral exports accounted for 37,1 per cent of South African merchandise exports in 1997. The total value of these mineral exports in 1997 was R51,9 billion. More detailed information on mineral exports and sales are presented in

Table 1.

In the national economy the industry contributed 7,8 per cent to the GDP. The industry furthermore contributed significantly to the national fiscus, both directly and indirectly. Directly through direct taxation the mines which amounted to R1,8 billion for the fiscal year 1997/98, this represented 1,2 per cent of the total tax revenue. Indirectly contributions were made through taxation paid by employees and industries that supply, or make use of the mining industries products.

Table 1 MINERAL SALES AND EXPORTS, 1997 (DATA AS AT JUNE 1998) [2]

Commodity	Export sales R1000	Total sales R1000	% Export to total sales
Gold	24 829 429	25 088 302	98,97
Platinum Group Metals	8 407 450	8 510 595	98,79
Silver	96 355	102 252	94,23
Chrome Ore	429 046	962 792	44,56
Copper	763 415	1 682 609	45,37
Iron Ore	1 619 345	2 088 395	77,54
Lead	153 771	153 771	100,00
Manganese Ore	585 529	893 783	65,51
Nickel	609 243	1 022 891	59,56
Zinc	0	273 788	0,00
Asbestos	68 004	72 056	94,38
Coal	8 603 001	16 288 881	52,82
Fluorspar	92 380	103 572	89,19
Limestone & dolomite	16 031	710 632	2,26
Miscellaneous*	5 583 385	6 214 988	67,97
TOTALS	51 856 384	66 169 307	78,37

Source: Minerals Bureau, Dept of Minerals and Energy

As can be seen from
Table 1 coal plays a significant role in the South African economy and is second only to gold in earning foreign exchange. As a result of a lack of alternative energy sources such as oil and large scale hydroelectric power, coal is the country's major energy source. By supplying 88 per cent of the commercial energy requirements, coal is also therefore a major contributor to economic growth and industrialisation. Of the 220,5 million tons produced in 1997, 157,1 million tons (74 per cent), was used domestically [1].

Escom's coal fired power stations, together with a few local utilities, consume 92.97 million tons in 1997. Sasol, the only successful commercial oil-from-coal producer in the world, consumed approximately 55 million tons in 1988, making it the second most important domestic user. Other major users include Iscor's metallurgical plants, the cement industry and the large municipalities.

Almost 90 per cent of the total saleable coal are produced from the Witbank/Highvelt coalfields, two of South Africa's 19 coalfields. In 1997 South Africa's economically recoverable coal reserves, estimated at 52 billion tons, ranked South Africa fifth in global terms [2]. Most of South Africa's coal is of a bituminous thermal grade, approximately 2,0 per cent are anthracitic and some 1,6 per cent are of metallurgical quality.

Over the past few years there has been a growth in demand for steamcoal coupled with a supply shortage caused by production, weather and labour problems that affected most steam coal exporters. in the late 1980s. These market conditions were beneficial to the South African coal producers. Of the 220 million tons of coal produced in 1997, about 63,9 million tons (26 per cent of the annual production) were exported, earning some R8,6 billion of foreign revenue.

South African mines tend to be relatively large and consequently have numerous underground sections. It is therefore not unusual for as many as 10 underground sections to be served by a single shaft. An individual mine will usually be dedicated to supply a specific power station or private contract. These requirements in turn dictate the overall production rates. Under normal conditions these remain fairly static. The emphasis of a productivity increase is thus not necessarily to increase the output from the mine, but rather to decrease the resources that are needed to extract the coal. This in turn leads to a decrease in the number of employees required, and is therefore met with resistance from the work force.

Another aspect of the South African coal mines is the diversity of mining methods employed. Three mining methods are used in the extraction of the coal. They are bord and pillar, pillar extraction and longwalls. With bord and pillar and pillar extraction, two mining methods are used. The first is conventional drill and blast and the second utilises mining machines (continuous miners or roadheaders) to extract the coal.

There was a major increase in the production from the coal mines between 1974 (64,6 million tons) and 1997 (220 million tons). This was a direct result of a significant increase in the mechanisation of the coal mines, with the introduction of mining machines and longwalls.

Although the number of longwall faces increased up to 1990, the trend has been reversed in later years, with more attention being given to continuous miner stooping and ribs pillar mining. The main motivation for this trend is that continuous miner sections are more flexible with regard to underground geological disturbances in the coal seam. An added advantage is that the capital expenditure per coal production unit is significantly lower.

During the past few years the incidence of labour disputes has increased considerably. This has forced management to spend a large amount of time and effort in resolving labour related problems. Wage demands have therefore been the major contributor to the escalation in production costs while increases in productivity have remained low.

This led research to be focused on continuous miners and roadheaders and ways to improve the production rates from these machines by developing a more efficient cutting process. To accomplish this more and more use was made of computer technology. It has become an accepted axiom in the mining industry that mechanisation of the mining process will significantly improve production. However, it should not be assumed that mechanisation at the same time inherently improves worker safety. In many cases different safety hazards are introduced with the new machinery that simply displace the hazards associated with manual mining. In addition to the demand for higher production there is thus a need to improve the safety and health of the operators.

BACKGROUND

During the 1970s the Chamber of Mines Research Organisation (COMRO) spent a great deal of time and resources on evaluating continuous miners. It was generally found that the coal in the South African collieries was harder and more abrasive than the coal in the countries from where the continuous miners were originally imported. Research was therefore aimed at improving the capacity of machines and developing a more efficient cutting process.

In 1985 Oberholzer [5], concluded that the availability of a continuous miner for cutting was fairly high. The emphasis of COMRO's research then changed from the machine capacity, to evaluating the manner in which the continuous miner was utilised. Following this, Oberholzer and Thorpe [6] investigated the cutting rates of continuous miners. They found that the cutting rate of a continuous miner varied significantly, in spite of the fact that the conditions within different sections, including tramming distances, were nearly identical. They further found the "unproductive" phase within the cutting cycle to be as high as 43 per cent of the total cutting time. This confirmed the assumption that production from a continuous miner was influenced more by external factors included in the overall mining process as opposed to its coal cutting ability. This was mainly attributed to the machine operator's ability and experience, and the techniques he used. These findings then formed the basis for the research work that was conducted from 1985.

Variations in the judgment of different operators appeared to be responsible for the different output rates. These variations, attributed to the human factor, directly affect the control of the sumping and shearing process, as well as the transportation of the coal. Time losses that can be attributed to the operator's influence tend to be small, but are, however, occurring continuously and their cumulative effect has a major influence on the total production loss of the section. The most important of these delays are due to:

Poor horizon controls, leading to premature pick damage, coal contamination, and an excessive amount of time spent on low cutting rates during roof and floor trimming.

Failure to control the sumping depth, and the subsequent inability to cut coal at the optimum rate and to synchronise coal cutting and coal transportation.

Low boom lift rates, due to operator caution and the inability to identify the correct sumping height due to poor visibility

To address the three problems areas identified, as mentioned above, a control system was designed [7]. The "total" control system consists of a horizon control system, an advance control system, the continuous miner operator, the machine controls and the required horizon. The horizon control addresses the boom lift times and control of the roof and floor horizon to which the coal seam is cut. The advance control, where the depth of sump is controlled, allowed a shuttle car to be filled with one sump and shear cycle. This resulted in the synchronisation of coal cutting and transportation of the coal in the section. By using only the visual indicators of the horizon and advance control system, the operator compared the actual position of the cutter head with that of the required position. If there is a difference between the two positions, the operator will close the loop by activating the machine controls and move the boom or the machine until the actual and required position are the same.

Further enhancements of the above described control system led to the development of the remote control systems that are part of all the mining machines found today. In order to effectively implement the remote systems, intelligent control systems on the machine had to be used to ensure the integrity and safety of the system as a whole. With these intelligent systems on board, flexibility and adaptability was available to fulfil most of the requirements of the mines. One of the most exciting of these requirements is a fully automated mining cycle (Auto-Cut) [???]. The process involves "teaching" the continuous miner to cut coal, the information obtained during each cutting cycle is constantly evaluated and refined, to ensure the mining machine is cutting at maximum performance at all times.

A further result of the introduction of intelligent controls on the mining machines was the need for online monitoring and reporting. This resulted in the development of a whole array of sensors and transducers that could be interfaced with the intelligent control systems. In addition research had to be done on methods of transporting the information from the mining equipment to the personnel requiring it [?????]. In Figure 1 the information requirements of the different levels in a mine is presented. The information requirements of the different levels are inverted when considering technical and operational information.

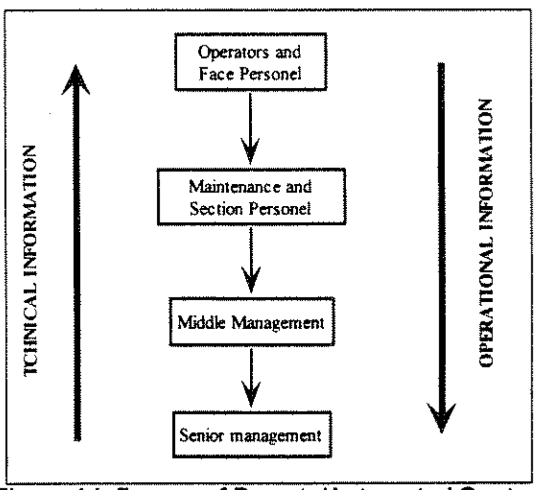

Figure 1 Influence of Remote/Automated Control

If a problem occurs with a mining machine, the people working at the face want to know the extent of the problem and where to fix it, management is only concerned that a problem has occurred. The same is true with operational information, management wants to know the utilisation of the machine and the costs of coal cut, while the operator is only concerned with the cutting coal.

A system was developed to supply management with information that will assist in improving productivity and reliability of mining machines. The core of the system is a data logger system that sends information from the mining machine underground to a location on surface. The system makes use of modems and the standard mine telephone cables. The system has the capability to be used as an on line time study tool, therefore, a production information system. The system is at present been adapted to suit the requirements of a mine that wants a one page production report from the system.

In the environmental area electronics have been used for a long time, for example the use of methanometers to test for the presence of methane gas. The use of multihead methanometers coupled to data loggers have been used to quantify the time and spatial distribution of methane in areas around the mining machines while cutting coal. By incorporating the information obtained at the working face with information about airflow in the section, a total environmental picture of the conditions in the section can be generated. This will then address a need that has been long outstanding in South Africa, namely reducing the influence of human error, the effects of which accumulate during the time from when something goes wrong in the section until emergency systems react.
The terms used by the mining industry in this area are open to different interpretations that lead to some confusion. In order to establish a common ground between researchers, mines, and manufacturers, the following definitions as used and accepted by the mining industry are presented [?]:

Remote control – The operation of mining equipment from a location off and distant from the machine being operated. This location may be within eyesight or in a remote place totally away from the machine. The primary purpose of remote control is to improve worker safety when the machine is operated under hazardous conditions. A man-machine interface is required from where the operator must initiate all machine actions.

Automation – Is the result of ensuring the integrity and safety of remote control systems. Through automation several of the various operational steps taken by a machine to accomplish its objective are combined under a pre-designed protocol. The automation process will improve the productivity of the machine and provide protection for the machine components, while minimising the interaction of the operator with the process. Although the operator is not necessarily eliminated, his efforts are reduced to supervisory rather than active control.

Robotics – A fully automated mining machine that can operate autonomously, with practically no interaction from a human. It is a combination of both remote control and automation. However, as the mining environment is so unpredictable, true robotic operation may not be viable or cost effective.

The following three basic reasons are commonly used and accepted for the adoption of automated-remote control equipment in the mining industry:

Improved safety - Equipment can operate in a hazardous location without jeopardising the safety of machine operators.

Increased productivity - At a time when revenue per ton is going down, the cost per ton is going up, making mining companies less profitable. Use of mechanised semi-automated equipment can significantly improve overall mining efficiency while lowering the production cost per ton.

Work health - Long term liability issues associated with the health of underground workers have made mine owners more aware of the impact of poor working conditions, and thus the desire to switch to more mechanised operations.

NEW HAZARDS

In the South African environment, as a result of our labour force and economical climate, automated mining machines still require a human interface. In order therefore to be able to improve productivity while at the same time improving worker safety the use of automation and remote control technology was essential. The introduction and use of this technology has, however, introduced new hazards into the mining of coal. These new hazards can be classified into human, technical and financial hazards. The boundaries between the hazards are not fixed but tend to overlap.

Human hazards

When operating remote control equipment, the operator is remover from the "safety" of his cab, and must now deal with powered equipment, exposed rotating parts and large moving objects in the confined space of a underground roadway.

One of the major concerns with the use of remote control equipment is the tendency of the operators to move into an unsafe position while operating the machine. Irrespective of the rules and regulations, the operator invariably moves into more dangerous areas when using a remote control system. To prevent the machine operator being run over or crushed by the machine being controlled, proximity protection is been developed. The system will be such that the remote controlled signals become inoperative and machine motions immediately stop and adopt a neutral mode when the operator moves from the control zone S_c and approaches the receiver, hazards zone S_H, within a predetermined radius, or the probability of the operator in the hazardous zone increases above a predetermined level [??]. The probability of the operator in the hazardous zone is given by (1) and the symbols are explained in Figure 2:

$$P = \frac{2(H + L + 2)}{(B \times Y) - (L \times H)} \qquad (1)$$

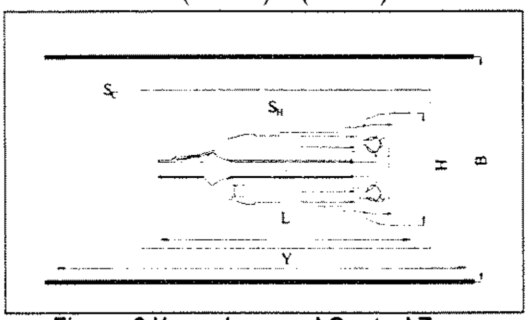

Figure 2 Hazardous and Control Zone

Another concern with the use of remote control and automated equipment is boredom that set in during the shift. Boredom has been identified as one of the more serious problems in industry today [??]. Boredom set in when the operator loses interest in the job, and time hangs heavy on his hands. Boredom and fatigue are closely related, boredom actually cause fatigue. While the excessive use of the nerves and muscles of the body cause fatigue, boredom is caused by a combination of the following factors:

- Lack of variety
- Lack of opportunity
- Inadequate sense of accomplishment
- Inability to control one's own work pace
- The need for superficial attention or non at all

All of the above factors are present when a mining machine is used in an automated remote control mode. To address this problem the operator should not continuously operate the machine for a full shift. Alternatively the remote control system should be designed to accommodate the boredom factor.

Technical hazards

One of the biggest technical hazards faced when using automated remote control systems is the accidental activation of the mining machine or the activation of the mining machine by more than one transmitter in the section. The operator at the machine is in neither of the two instances in control of the machine, he can therefore not take any action to avoid accidents. The results is usually of a serious nature as personal in the section can be killed or excessive damage can be caused to the machine, there will be a production loss as the incident will have to be investigated.

The equipment used is highly sophisticated and should only be repaired by trained specialists. As a result of the costs that are charged for repairs, untrained people open the equipment to try and repair it. Unauthorised repairs usually result in costly damage to the systems. By opening the equipment in the face area, as has occurred in the past, a real danger of explosions exist that could have catastrophic consequences.

In the environmental arena the use of methanometers has become so familiar that they are ignored or bypassed when they interfere with the production of the coal. A further problem with the use of electronic gas instruments is that they are often used to "detect" gasses that they are not calibrated for or used incorrectly.

In resent years advances in computer technology have been increasingly used to fulfil control tasks. As the dependency of operators on the PC controlled equipment increased, the development of more and more software intensive systems are required. However, the utilisation of software as part of the control systems has introduced new failure modes and created problems in the development of safety-critical systems. There is therefore a need to be able to effectively assess the safety of software embedded into mining machinery, as there has always been a need to assess the safety of the mechanical, electrical, etc aspects of a machine.

The biggest technical hazard is not related to the equipment but to the people involved in the decision making of the requirements and standards that is to be applied to the equipment. The same is true for the software area where non-experts define specifications. This non-expert involvement in automation, remote control and software is not only costly on the long term, when projects have to be redone, but also dangerous as they don't have the experience to make correct decisions.

Financial hazards

As a result of the increased technology, the mining industry has moved from a labour intensive to a capital-intensive industry during the last few decades, and therefore the optimum utilisation of capital becomes critical for survival in the industry. The importance of machine maintenance has thus increased accordingly and is playing a more important role in the running of the industry. A paradigm shift, from where maintenance is not the fixing of things, but the implementation of a practice where maximum value is extracted from equipment assets has therefore been made. Maintenance optimisation is not necessarily about lowering gross maintenance costs, but about finding the optimum level which ensures maximum realisation of the productive potential. However, unless there is a tangible change in the bottom line i.e. increased revenue through better utilisation and/or reduced costs, there will be little improvement in the long term. Increased equipment reliability and support is therefore one of the key issues that are focused on.

As the mines see the automation and remote control equipment as an integral part of the mining machine they depend on the Original Equipment Manufacturer (OEM) of the machine to provide support for these electronic components. The development of these electronic systems are, however, highly specialised and is usually not done by the OEM, but bought from specialists in the field. As the mines depend on the OEM to maintain the systems they are charge exorbitant premiums for the repair and maintenance. Furthermore the OEM only acts as a middleman between the mine and the specialist, therefore the turnaround time on the repair of systems forces the mine to keep additional stock of these components or make use of service exchange units at great cost. This snowball effect of escalating cost caused by the OEM will eventually result in mines having to closedown, as they can not afford the equipment to mine the coal with. To overcome this problem of the users (mines) been kept to ransom by the OEM they should force the OEMs to standardise on off the self control and automation equipment or open architecture components that are available from more that one source.

RECOMMENDATIONS FOR FUTURE SYSTEMS

There are three needs that the mines needs addressed. The first is to increase the productivity of there mining sections the second is to obtain reliable information about all the conditions underground and the third is to ensure the safety of the operators underground. To address the above mentioned needs, the following concepts need to be investigated:

- The system must have two way communication between the operator and the mining machine. This is to provide him with visual information to understand what is going on with the mining machine itself and must provide the facility to control the machines actions.
- A reliable navigation system that will provide information about the mining machine's heading and location at all times. The navigation data required by the system includes position, attitude (heading/pitch/roll), angular rate accelerations and velocities. It must provided means to keep the mining machine within the desired part of the coal seam.
- Data communications must provide the link between the activities of the machine and a computer located at a convenient control station.
- With the increased complexity of the equipment used as part of a automated remote control system a need has arise for a diagnostics function on the equipment. It must be aimed at assisting first line maintenance of the equipment. This is a necessity, as the mine does not have the skilled labour to maintain the equipment in an optimum state.
- Software must be developed in such a way that it is impossible or extremely unlikely that its behaviour will lead to a catastrophic failure of the system. In order to achieve this, the probability and the severity of a failure must be considered and catered for

during the development of the software. An integral part of all software should be self-tests and start-up tests that ensure the integrity of the system and the software at all times.

- By combining the control system and the electro-hydraulics of the machine, it is possible to set interlocks, which, will cut out the operation of the machine if unsafe conditions arise. With this approach, the system will be an integral part of the continuous miner and will force the operators to follow safer operating practices.

- During the design phase of systems hardware redundancy and fail-safe circuitry must form an integral part of the design. To successfully achieve this the use must be made of experts with practical experience of the environment the equipment is to be used in.

CONCLUSIONS

In the past the trend has been towards larger and more powerful machines, but practical limits for present mining methods and conditions (sizes) have now been reached. In order to achieve productivity growth, other approaches must now be followed and/or investigated. It is felt that automation is a strong contender, as a result of the phenomenal growth that has occurred in the sensing, control and computing technologies over the past decade. With the increase in automation goes an increased demand for communication of information from underground.

In order to fully develop and realise the benefits of automation, fundamental changes are required in the way in which mines are both managed and operated. Technical management of mines has primarily been the responsibility of generalists. Dealing with the increased complexity of mine related technical problems and their solutions will require a team approach that draws upon the strengths of individuals trained in specific disciplines. Even the section crews must learn new operational and maintenance routines to effectively use automated equipment.

The area that needs attention is the training of operators and supervisors working with automated remote control systems. The tendency is to provide an operator with a system and expecting him to produce coal. The advantages and the benefits are never explained to the operator this leads to a resistance towards the systems and accidents. The accidents are the result of the operators not been made aware of the consequences of the actions they take when using a remote control.

When automation and remote control systems are installed they should be subservient to the processes being used by the mine rather than forcing the mine systems to become subservient to the systems. Unless this is done, the inherent resistance will make the systems fail, as they will be resented rather than be seen to be assisting the workers in the section. In any control system in which the human plays an integral part, the human will strive to change the system, in any possible way, so that he becomes the determining factor in the control loop.

The mining machine OEMs is not necessarily the OEM that developed the automation and remote control systems. In order to have systems that address the needs of the mines, a relationship should be established between the system developers and the mines.

In a world where the competition is constantly increasing, the mining industry is under severe pressure to reduce costs. In the present situation where the mines is at the mercy of the OEMs, the cost of automation and remote control systems will start to diminish the benefits that are obtained from the systems.

REFERENCES

[1] Anon, "Statistical Tables 1993, " Published by The Chamber of Mines of South Africa.

[2] Anon, "Facts and Figures - 1989," Published by The Chamber of Mines of South Africa.